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Wind Energy Based Single- Stage Three Level Isolated Ac/Dc Pfc Converter

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Abstract:
For low-cost isolated ac/dc power converters adopting high-voltage dc-link, research efforts focus on single-stage multilevel topologies. This paper proposes a new single-stage three-level isolated ac/dc PFC converter for high dc-link voltage low-power applications, achieved through an effective integration of ac/dc and dc/dc stages, where all of the switches are shared between two operations. With the proposed converter and switching scheme, input current shaping and output voltage regulation can be achieved simultaneously without introducing additional switches or switching actions. In addition, the middle two switches are turned on under zero current in discontinuous conduction mode operation, and the upper and bottom switches are turned on under zero voltage. Due to the flexible dc-link voltage structure, high power factor can be achieved at high line voltage. for dc ripple reduction the ac source is designed with a wind turbine system. The above work was carried out by using mat lab software.

Key words: wind energy, power factor correction, three-level single-stage PFC converter.

I .INTRODUCTION:
The power supply unit is an essential circuit block in all electronic equipment. It is the interface between the ac mains and the rest of the functional circuits of the equipment. These functional circuits usually need power at one or more fixed dc voltage levels. Switch mode power supplies (SMPS) are most commonly used for powering electronic equipment since they provide an economical, efficient and high power density solution compared to linear regulators. The devices generally used in industrial, commercial and residential applications need to undergo rectification for their proper functioning and operation. They are connected to the grid comprising of non-linear loads and thus have non-linear input characteristics, which results in production of non-sinusoidal line current. Also, current comprising of frequency components at multiples of line frequency is observed which lead to line harmonics. Due to the increasing demand of these devices, the line current harmonics pose a major problem by degrading the power factor of the system thus affecting the performance of the devices. Hence there is a need to reduce the line current harmonics so as to improve the power factor of the system.This has led to designing of Power Factor Correction circuits. Power Factor Correction (PFC) involves two techniques, Active PFC and Passive PFC. Here active power factor circuit Converter was designed for improving the power factor. This converter is to observe the effect of the active power factor corrector on the power factor. The advantage of using power factor correction circuits is that to obtain better line regulation with appreciable power factor. Active PFC can be implemented by controlling the conduction time of the converter switches to force the ac current to follow the waveform of the applied ac voltage.Passive PFC is the simplest and most straightforward method to eliminate input current harmonics. This is achieved by using passive reactive elements either at the input or at the output side of input rectifier employed in the design of AC-DC converter. Advantages of this method are high efficiency, low EMI and simple implementation. However, the main drawbacks particularly at the low frequency are the size, weight and cost. AC-DC power converters are required to operate with high power factor (PF) and low total harmonic distortion (THD) for

improved grid quality and full capacity utilization of the transmission lines.

In order to operate at high frequency and reduce the size of the circuit, high frequency two-stage active PFC converters have been proposed. In this architecture, a front-end ac/dc PFC converter is operated with a switching frequency in the order of tenths to several hundred kHz for converters with Si semiconductor devices, and from several hundreds of kHz to tenths of MHz with wide-band gap devices, to shape the input current close to sinusoidal waveform in phase with the grid voltage. The second stage dc/dc converter provides the galvanic isolation and output voltage regulation. The controllers of the two stages are completely independent. The flexibility in control allows optimizing power stages, fast output voltage regulation and operating with high PF and low THD. However, this method comes with the expense of more components and larger size. Moreover, the constant switching losses such as parasitic capacitance losses associated with power switches reduce the efficiency of the converter at light load condition.

A cost-effective approach to reduce the number of switches is to use single-stage ac/dc converters. In single-stage PFC converters, the front-end PFC stage and dc/dc stages are integrated and their operations are performed in a single-stage, basically, by sharing some of the switches and control scheme. An energy storage unit, capacitor or inductor, is located in between two stages, acting as a power buffer and providing sufficient hold up time. Numerous PFC ac/dc single-stage topologies have been proposed in literature, particularly, operating in discontinuous conduction mode (DCM) for simple yet effective PF control. Majority of the proposed single-stage converters are proposed for low-power applications, where a fly back or forward converter derived topologies are used to achieve input current shaping and output voltage regulation. These converters offer cost-effective solution for low-power applications; however, they suffer from excessive voltage/current stresses on the switches, and are suitable for power levels lower than 200 W.

For medium to high power applications, the research efforts have focused on ac/dc single-stage full-bridge (SSFB) converters. Current-fed SSFB converters deploy a current shaping inductor connected to the input of the diode-bridge achieving high PF. However, due to the lack of dc bus capacitor on the primary side of the transformer, the dc bus voltage is subjected to excessive overshoots and ringing. Furthermore, the output voltage contains high amplitude second-order harmonic oscillating with twice the line frequency, which restricts their operation. Voltage-fed SSFB converters do not exhibit the drawbacks of current-fed SSFB converters, where a large capacitor is located on the primary side dc bus. However, the dc bus voltage remains unregulated and it can be excessive at light load condition, as both input current shaping and output regulation are achieved with a single controller.In the literature, resonant converters adopting variable switching frequency have been proposed. In these converters, it is difficult to tune the resonant tank components over a wide load range, and optimize EMI filter .In majority of these aforementioned converters, the output current ripple becomes very large and the converter operation may transit to DCM mode. In two-level SSFB converters, the switches are exposed to high voltage stresses; thus, dc-link voltage is typically set close to 400V.In multilevel configurations, the voltage stresses across the switches are significantly reduced. Quite recently, single stage three-level (SSTL) converters have been studied, which allow a flexible dc-link voltage in the range of 400 to 800 V.

In a resonant SSTL converter is proposed to alleviate the drawbacks associated with SSFB converters, while reducing the voltage stress on the switches. In a recent publication a three-level converter is integrated with the PFC boost stage by sharing the bottom switch. It is aimed to decouple the dc bus voltage and output voltage controllers, while the input current is adjusted with a constant duty cycle in DCM mode. The duty cycle of the bottom switch shapes the input current as well as is used to transfer energy from dc bus to output, simultaneously. The required duty cycle is the sum of the values achieved from individual PI controllers. The output voltage regulator sets the base duty cycle, while the PI controller

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of dc bus voltage regulator extends the duty cycle for the bottom switch. This topology alleviates most of the problems associated with SSFB converters, operated at constant switching frequency with a flexible dc-link voltage.

However, two auxiliary diodes are added to

1) Prevent input current to flow through the midpoint of split dc bus capacitors,

2) Enable a freewheeling path for primary side current when the energy in the leakage inductance is transferred to the bottom capacitor.

In addition, a third auxiliary diode is added to serve as a boost PFC diode. Although the converter has been proven to work, it can further be integrated for lower power applications by removing the auxiliary diodes and developing a phase shifted modulation scheme. This study proposes a new SSTL isolated ac–dc PFC converter for high dc-link voltage and low-power applications, achieved with complete integration of two stages, where all of the switches are shared between input current shaping and output voltage regulation stages. In comparison with the existing three-level single-stage topologies, the proposed converter offers minimum number of components as of three-level dc/dc converter, and does not require any auxiliary circuit other than a diode bridge and an inductor. The proposed topology can serve as a low cost power electronic interface intended for applications requiring high-voltage dc-link.

This feature allows having lower output current ripple and less distorted input current even at light load condition. In addition, the middle two switches are turned ON under zero current in DCM operation, and the upper and bottom switches are turned on under zero voltage, which increases the efficiency of the converter in comparison to hard-switched ac/dc single-stage converter. Furthermore, higher PF can be achieved at high line voltage due to the flexible dc-link voltage structure.

II.WIND ENERGY:

Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth’s rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth’s atmosphere which in turn will cause the temperature of the earth’s surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

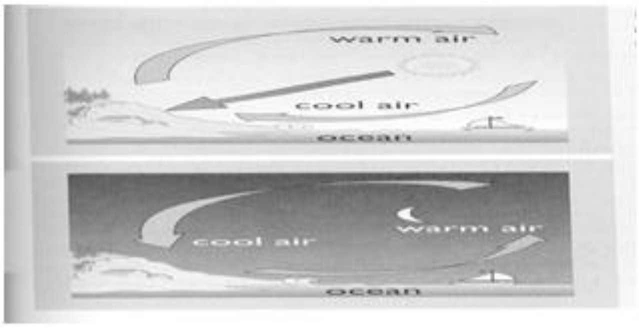

Figure 1 : Formation of wind due to differential heating of land and sea

Features of wind power systems:

There are some distinctive energy end use features of wind power systems

i. Most wind power sites are in remote rural, island or marine areas. Energy requirements in such places are distinctive and do not require the high electrical power.
ii. A power system with mixed quality supplies can be a good match with total energy end use i.e. the supply of cheap variable voltage power for heating and expensive fixed voltage electricity for lights and motors.

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iii. Rural grid systems are likely to be weak (low voltage 33 KV).Interfacing a Wind Energy Conversion System (WECS) in weak grids is difficult and detrimental to the worker safety

There are always periods without wind. Thus, WECS must be linked energy storage or parallel generating system if supplies are to be maintained

Power from the Wind:

Kinetic energy from the wind is used to turn the generator inside the wind turbine to produce electricity. There are several factors that contribute to the efficiency of the wind turbine in extracting the power from the wind. Firstly, the wind speed is one of the important factors in determining how much power can be extracted from the wind. This is because the power produced from the wind turbine is a function of the cubed of the wind speed. Thus, the wind speed if doubled, the power produced will be increased by eight times the original power. Then, location of the wind farm plays an important role in order for the wind turbine to extract the most available power form the wind.The next important factor of the wind turbine is the rotor blade. The rotor blades length of the wind turbine is one of the important aspects of the wind turbine since the power produced from the wind is also proportional to the swept area of the rotor blades i.e. the square of the diameter of the swept area.

Hence, by doubling the diameter of the swept area, the power produced will be fourfold increased. It is required for the rotor blades to be strong and light and durable. As the blade length increases, these qualities of the rotor blades become more elusive. But with the recent advances in fiberglass and carbon-fiber technology, the production of lightweight and strong rotor blades between 20 to 30 meters long is possible. Wind turbines with the size of these rotor blades are capable to produce up to 1 megawatt of power.

The relationship between the power produced by the wind source and the velocity of the wind and the rotor blades swept diameter is shown below.

$$P_{wind} = \frac{\pi}{8} dD^2 v_{wind}^3$$

The derivation to this formula can be looked up in [2]. It should be noted that some books derived the formula in terms of the swept area of the rotor blades. Thus, in selecting wind turbine available in the market, the best and efficient wind turbine is the one that can make the best use of the available kinetic energy of the wind.

III. PROPOSED THREE-LEVEL SINGLE-STAGE PFC CONVERTER:

The performance of voltage-fed, SSPFC full-bridge converters can be improved if the limit on the dc bus voltage (typically < 450 V) is relaxed. This is not something that can be done for SSPFC full-bridge converters that are based on two-level topologies, but this can be done for converters that are based on three level, multilevel topologies as the primary-side switching devices of these converters are exposed to half the peak voltage stress that those of two-level converters are. As a result, the dc bus voltage limit can be doubled for multilevel converters, but the peak voltage stress of the switches is the same as that of two-level type topologies. The steady-state characteristics of the converter are determined by mathematical analysis and are used to develop a procedure for the design of key converter components. The feasibility of the new converter is confirmed with results that were obtained from an experimental prototype.The proposed converter, shown in figure consists of an AC input section, a three level DC-DC converter, and dc link circuitry that is based on auxiliary windings taken from the main power transformer and that contains an inductor Lin and two diodes.

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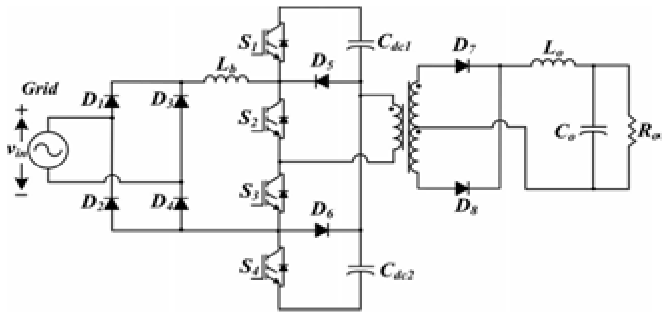

Figure 2: Proposed three-level single-stage PFC ac–dc converter

Switching scheme of the conventional three-level isolated dc/dc converter is given in Fig. (b). In this conventional scheme, the duty ratios of S2 and S3 are fixed close to 50% for simplicity in control and to ensure upper or lower three switches are not turned ON simultaneously as this would cause short-circuit through dc-link capacitors. Overlapping these two signals, as long as short-circuit condition is avoided, has no impact on the operation of the circuit. Similar to that in the conventional scheme, zero voltage is applied across the primary side of the transformer. This modified switching scheme is presented in Fig. (c). When a boost inductor and a diode bridge is added to the nodes as in Fig. (a), the overlap of gate signals of S2 and S3 enables applying input voltage across the boost inductor.The switching scheme of the converter is given in figure. The switches S2–S3 , and S1–S4 have 180° phase shift with respect to each other. The duty ratios of S2–S3 should be greater than 0.5 such that two signals overlap. Here, the circuit is explained considering that input inductor current is discontinuous and the switching scheme is as follows; S1 is turned on right after S3 is turned OFF, and similarly, S4 is turned on when S2 is turned OFF. A dead-time should be inserted in between the turning ON instant of S1 and turning OFF instant of S3, and likewise between switching of S2 and S4 to avoid short-circuit

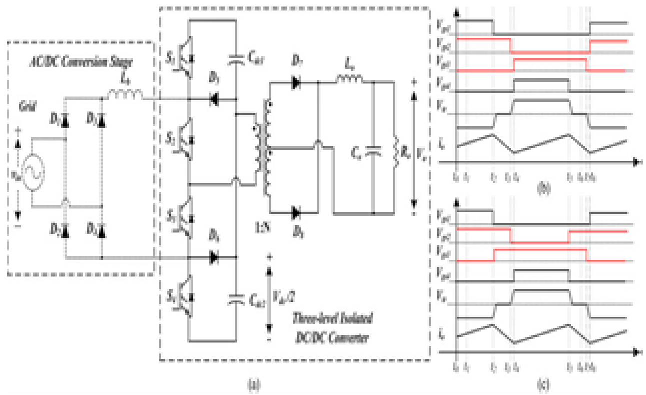

Figure 3: 2the proposed single-stage PFC converter (a) topology, (b) switching scheme of the conventional three-level dc/dc converter, and (c) modified switching scheme.

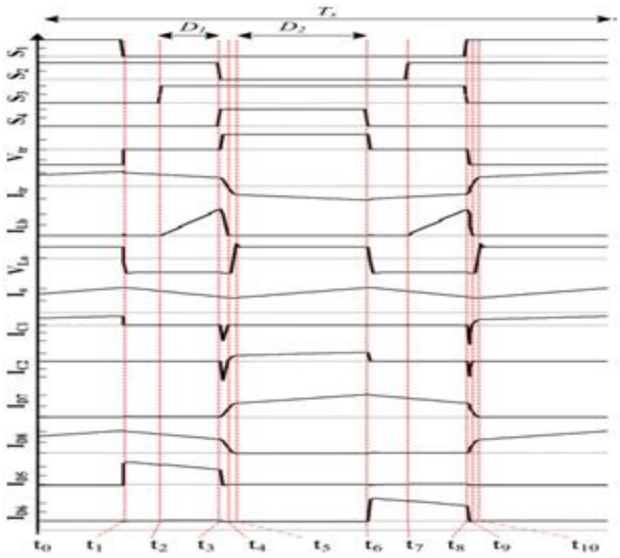

Figure 4: Switching scheme of the proposed integrated three-level ac–dc converter

Operation Modes:

The operation modes of the circuits are explained in this Section.

Mode 1 [t0 < t < t1]:

In this mode, both S1 and S2 are on. The upper capacitor, C_{dc1}, discharges to the load by applying $-V_{dc}/2$ to the primary side of the transformer. The primary side current increases linearly under constant voltage. $D8$ conducts at the secondary side of the transformer. The voltage across the output inductor is $V_{Lo} = V_{dc}/2N - V_o$. In this mode, the boost inductor, *Lb,* does not interfere to the operation of the circuit. During this mode1, switches S1 and S2 are ON and energy from the dc-link capacitor *C*1 flows to the output load. Since the auxiliary winding generates a voltage that is equal to the total dc-link capacitor voltage (sum of *C*1 and *C*2), the voltage across the auxiliary inductor is the rectified supply voltage. This allows energy to flow from the ac mains into the auxiliary inductor during this mode.

Mode 2 [t1 < t < t2]:

At *t* = *t*1, S1 is turned OFF and S2 is kept on. The current in the leakage inductance conducts *D*5 and the primary side current freewheels; hence, zero voltage is applied across the primary side of the transformer. The output inductor voltage is equal to −*V*o . The output inductor current decreases linearly.S1 is OFF and S2 is ON during this mode 2, shown in Fig 4. The energy stored in *L*in during the previous mode is completely transferred into the dc-link capacitor. The amount of stored energy in the auxiliary inductor depends upon the rectified supply voltage. This mode is a freewheeling mode as the primary current freewheels through S2 and*D*1 and the output inductor current freewheels through both secondary diodes. This mode ends when the current in *L*in, *i*Laux, reaches zero.

Mode 3 [t2 < t < t3]:

At *t* = *t*2, S3 is turned on, while S2 still remains on. The primary current continuous to freewheel and zero voltage is applied across the primary side; hence, the output inductor current continuous to decrease under output voltage. Meantime, *V*in is applied across *Lb* , and input current increases lin

Mode 4 [t3 < t < t5]:

In the beginning of this mode, S2 is turned OFF, S4 is turned ON, while S3 is kept on. Within this time interval, the following two operations are completed. The energy stored in the input inductor is transferred to the dc-link capacitors. The inductor current decreases linearly under *V*in − *V*dc. Meantime, *V*dc/2 is applied across the primary side of the transformer. The current in the leakage inductance is transferred to *C*dc2. This causes the output current to commute from *D*8 to *D*7 . At the end of this time interval, the energy in the input inductor is completely transferred to the dc-link capacitors and the commutation of the output diodes is completed. Depending on the dc bus voltage, and input current, one of these operations ends earlier than the other one. In this case, the energy stored in *L*b is transferred to the dc-link at *t* = *t*5 . Then, the current commutation from *D*8 to *D*7 is completed at *t* = *t*6

Mode 5 [t5 < t < t6]:

*C*dc2 discharges over to the load and *V*dc/2 are applied across the primary side of the transformer. The voltage across the output inductor is *V*Lo = *V*dc/2*N* − *V*o. The input current remains at zero in DCM mode. This mode is the same as Mode 1 except that S3 and S4 are ON and energy flows from capacitor *C*2 into the load.

Mode 6 [t6 < t < t7]:

At *t* = *t*6, S4 is turned OFF, and only S3 is on. This allows leakage current to freewheel through *D*6, and zero voltage is applied to the primary side. The output current decreases linearly under −*V*o .This mode are the same as Mode 2 except that S3 is ON.

Mode 7 [t7 < t < t8]: At *t* = *t*7, S2 is turned ON. The energy from the input is stored in the inductor. This is similar to Mode 3, except that this time the primary side current is opposite to that in Mode 3 and freewheels through*D*6.

Mode 8 [t8 < t < t10*]:*

At the beginning of this interval, S3 is turned OFF, S1 is turned ON, and S2 remains ON. This mode is similar to Mode 4, where the stored energy in the inductor is transferred to the dc bus capacitors and−*V*dc/2 is applied to the primary windings,in the mean time the output inductor commutates from D7 to D8.

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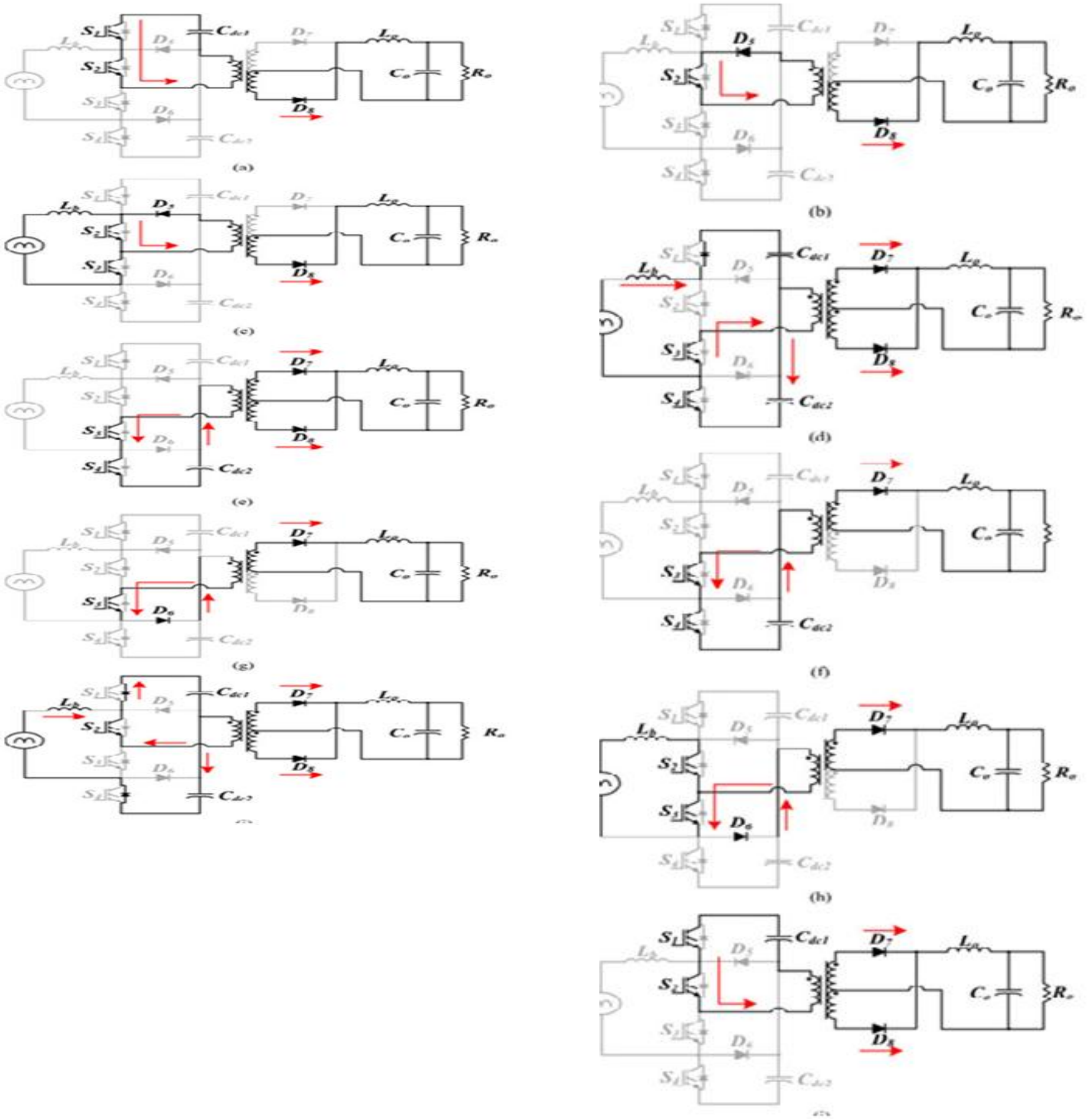

Figure 5: Operation modes of the converter. (a) Mode 1: t0 < t < t1. (b) Mode 2: t1 < t < t2. (c) Mode 3: t2 < t < t3. (d) Mode 4: t3 < t < t4. (e) Mode 4: t4 < t < t5. (f) Mode 5: t5 < t < t6. (g) Mode 6: t6 < t < t7. (h) Mode 7: t7 < t < t8. (i) Mode 8: t8 < t < t9. (j) Mode 8: t9 < t < t10

IV. SIMULATION AND RESULTS:

The results of the proposed model were obtained using MATLAB?SIMULINK. The simulink models are

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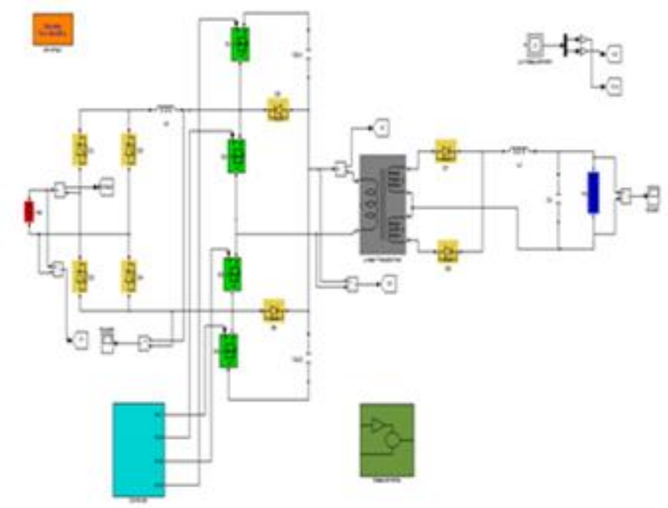


Figure 6: Simulink model without wind turbine

The block diagram model of wind turbine is

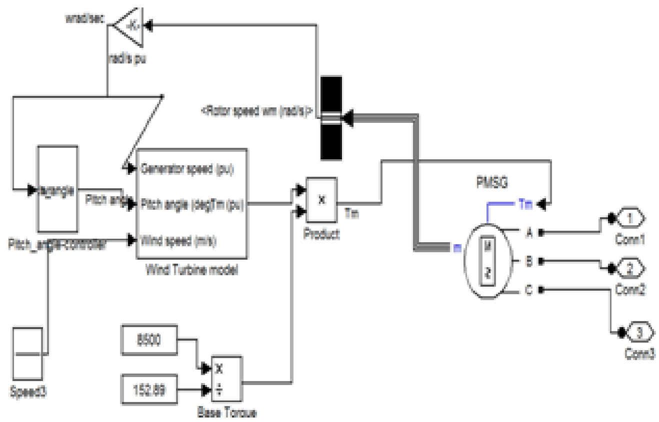


Figure 7: wind turbine model

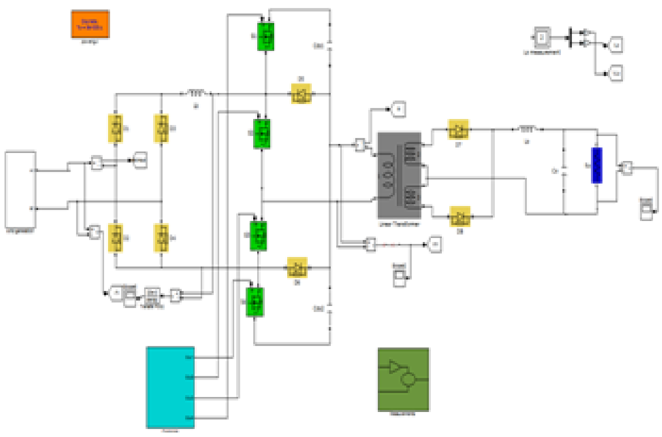


Figure 8: simulink model with wind turbine

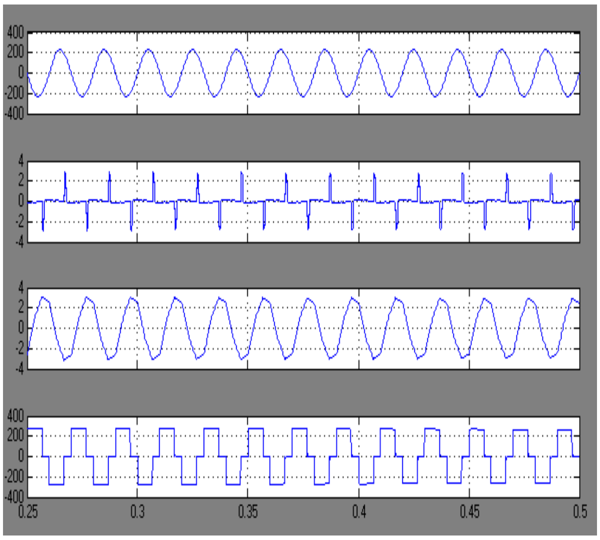
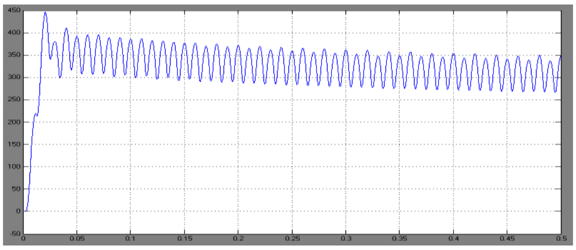
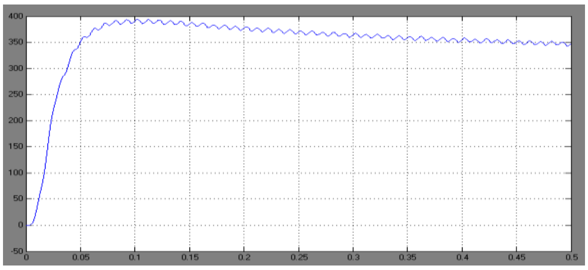


Figure 9: waveforms of the proposed model



DC Voltage without wind input



DC Voltage with wind input

V. CONCLUSION:

In this, a three-level single-stage PFC ac/dc converter is proposed for low-power applications. The proposed converter exhibits high PF with less number of switches/diodes, operated at constant duty ratio. A PFC inductor and a diode bridge are added to the conventional three-level isolated dc/dc converter, while the switching scheme is modified to be compatible with single-stage operation. The input current ripple frequency is twice of the switching frequency contributing to using smaller PFC inductor. Two independent controllers, in favor of

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shaping the input current and regulating the output voltage, are adopted which simplifies the design and control of the circuit. The tradeoff between the PF and overall efficiency in the case of adopting a variable dc-link voltage is analyzed through developed loss model. By replacing with source with wind energy the cost is reduced and the output ripples are reduced.

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